Performance Assessment of Vision Based Hazard Avoidance During Lunar and Martian Landing

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1. Introduction

Future exploration missions envisage landing on planetary surfaces that are not well known apriori, or in areas that are not hazard free. Landers also tend to become smaller and lighter, not so robust to surface hazards.

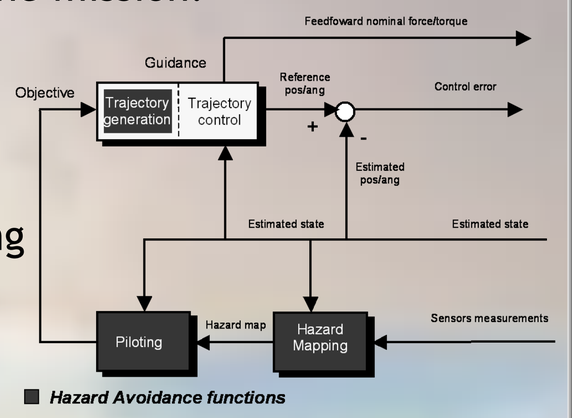
Autonomous pinpoint soft-landing systems that include Hazard Avoidance (HA) capability are therefore required to guarantee safe landing.

Within the context of several ESA's projects, Deimos Engenharia has been responsible for the development and testing of a Hazard Avoidance system.

2. Hazard Avoidance Concept

The HA system comprises the following functions:

- **Hazard Mapping**: detects hazards using image processing algorithms applied to optical images of the terrain taken by a camera. Shadows, high slopes, and large boulders constitute terrain features that endanger the mission.
- **Piloting**: refers to the concepts of data fusing, planning and decision-making used for the selection of a safe landing site (LS).
- **Guidance**: refers to the concepts used to steer the spacecraft till the LS.



HA functions within overall GNC system context

3. Performance Assessment Overview

Two mission scenarios:

- **Mars scenario**, based on Mars Sample Return
- **Moon scenario**, based on Lunar Lander Mission

Demanding conditions for the vision-based Hazard Avoidance system (very low Sun elevation angle).

The HA algorithms have been tested using a **landing simulator** enabling six degrees of freedom, high fidelity, closed-loop testing in a planetary landing scenario.

The test cases consist in simulating the landing mission for each scenario, targeting a nominal LS that is unsafe, and checking if a retargeting is commanded towards a safe LS.

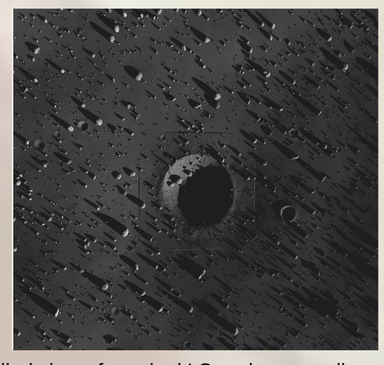
4. Terrain Characteristics

Challenging terrain used to test HA operation:

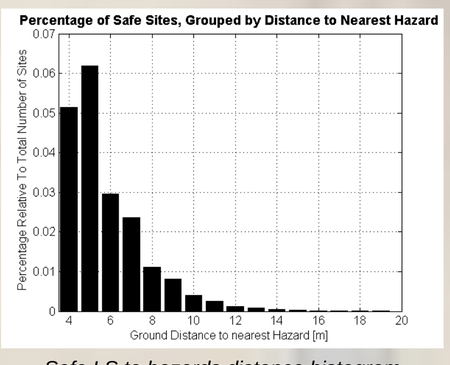
- Shallow illumination causes large shadows
- Very high number of dangerous boulders

In Moon scenario 45% of terrain is unsafe.

Histogram of the distance between each safe landing site and the nearest hazard illustrates that only **very few safe locations have a reasonable amount of clearance** to hazards. Sites with a clearance above 15m are almost non existent.



Detailed view of nominal LS and surrounding area.



Safe LS to hazards distance histogram

5. Test Results

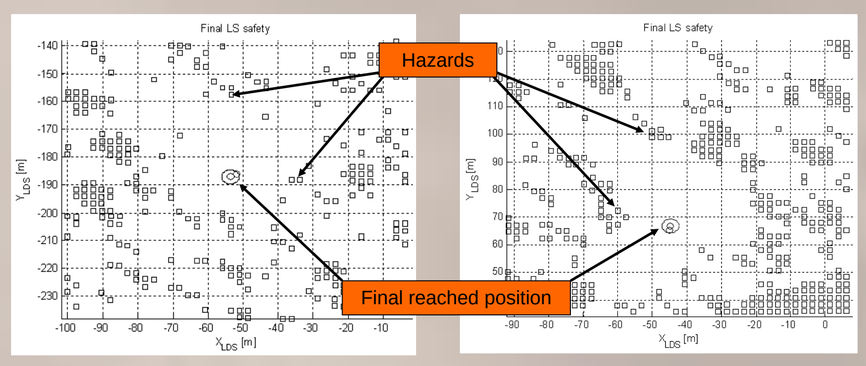
The HA system operation was simulated in both scenarios.

The nominal LS targeted at the start of landing simulation is unsafe, but the **system commands 2 retargetings** which bring the lander to a **safe LS**:

- First retargeting was commanded at the early phase of landing, **targeting a globally safe area**.
- Second retargeting **diverted the lander from smaller hazards** only visible late in the descent.

Final selected LS are in the **center of relatively large clearings**, with good clearance to hazards:

- Mars scenario: >13m
- Moon scenario >11m



Safety level of final reached position: Mars (left) and Moon (right).
Circles represent final selected/reached positions; squares mark hazardous locations.

6. Conclusions

The presented HA system is currently being developed in order to **consolidate the design** and **increase its maturity**, with the ultimate objective of having a definitive implementation in a landing mission.

The presented test cases demonstrate that the system is capable of **selecting a landing site** that is, not only **safe**, but also **among the best available** for landing. When comparing the clearance of the final reached position with the hazard distance histogram, it can be seen that the LS indicated by the system is **within the 1% best sites** available in the terrain.

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